ESTCP
Cost and Performance Report

(EW-201017)

Bi-Level Demand-Sensitive LED Street Lighting Systems

October 2013

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ACRONYMS

AIRR	adjusted internal rate of return
BLCC	building life-cycle cost
CCT	correlated color temperature
CO_2	carbon dioxide
CRI	color rendering index
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
fc	footcandle
ft^2	square foot
HID	high intensity discharge
HPS	high-pressure sodium
IENSA	Illuminating Engineering Society of North America
EK	degrees Kelvin
kWh	kilowatt hour
lbs	pounds
LCC	life-cycle cost
LED	light emitting diode
mg	milligram
MILCON	military construction
NAVFAC	Naval Facilities Engineering Command
NFW	NAVFAC Wash
NIST	National Institute of Standards and Technology
NPV	net present value
NSWC	Naval Surface Warfare Center
NSWCCD	Naval Surface Warfare Center Carderock Division
OLC	outdoor lighting controller
SIR	savings to investment ratio
SPAWAR	Space and Naval Warfare Systems Command
UFC	Unified Facilities Criteria

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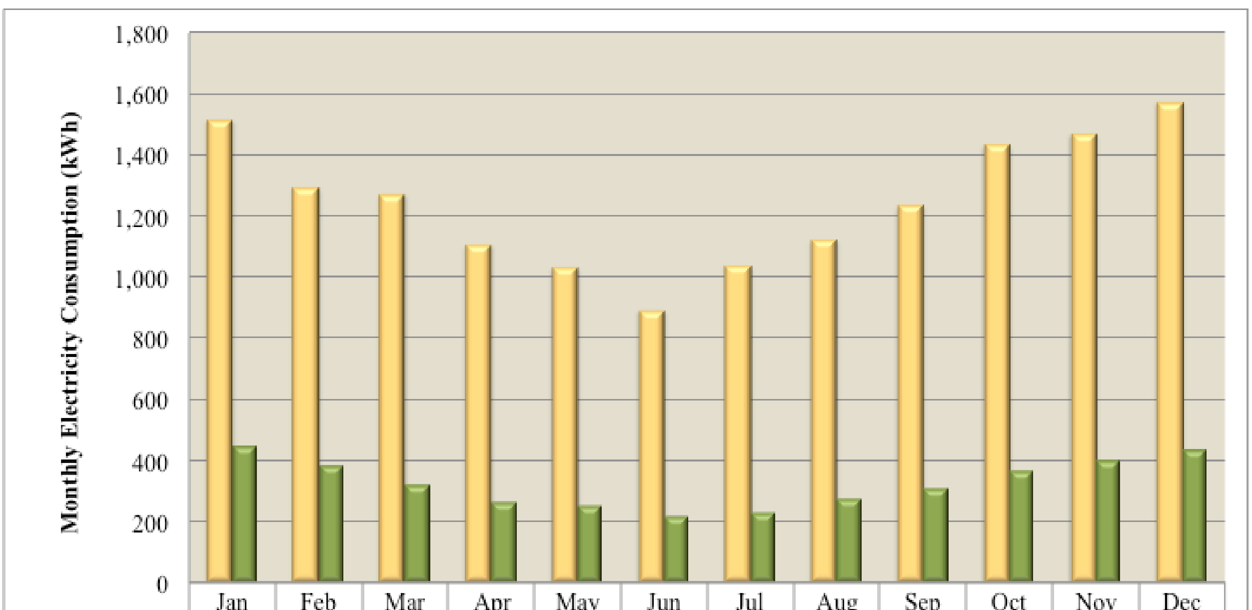
EXECUTIVE SUMMARY

This report documents a solid-state lighting technology demonstration with a demand-sensitive feature at the Naval Surface Warfare Center (NSWC), Carderock Division (NSWCCD) in West Bethesda, MD – in which light-emitting diode (LED) luminaires were substituted for existing High Pressure Sodium (HPS) street lighting units. This project was supported by the Department of Defense (DoD) under the Environmental Security Technology Certification Program (ESTCP).

During the course of the project, Virginia Tech and Old Dominion University, working in collaboration with Echelon Corp., developed, deployed and evaluated operational performance of a smart bi-level demand-sensitive LED lighting system for outdoor street lighting applications that allows dimming as well traffic sensing capability through a centralized controller. The existing eight units of HPS lamps were monitored for 1 year to capture their electrical energy consumption and operational performance, including illumination level and color rendition index. The set of LED lamps, together with their sensing and control unit, were then installed; and post-installation monitoring was performed during the subsequent year.

Results indicate a significant reduction in energy usage at about 74% electricity savings with the conversion of HPS to the demonstrated LED street lighting system. This is shown in Figure 1, where monthly electricity consumption (kilowatt hour [kWh]) of the HPS and LED street lighting systems during the monitoring period is compared. The data were recorded during a series of monitoring periods between January and December 2011 for the HPS system, and between January and December 2012 for the new LED system.

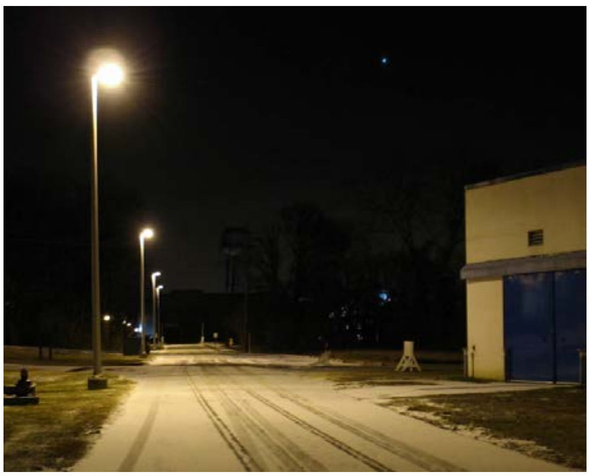


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HPS (2011)	1,514	1,290	1,270	1,103	1,030	890	1,034	1,119	1,232	1,431	1,468	1,572
LED (2012)	444	385	319	264	253	218	232	275	309	364	397	433

Figure 1. Monthly electricity consumption (kWh) of the HPS and LED systems.

The annual electricity savings of the LED as compared to its HPS counterparts were recorded at 11,060 kWh, which can be translated to avoided carbon dioxide (CO_2) emissions of 16,081 pounds (lbs) during the same period. The new LED-based system is expected to pay back its investment within 6 years with the savings-to-investment (SIR) ratio of 2.15 and the adjusted internal rate of return (AIRR) of 9.77%.

Feedback from individuals at the NSWCCD indicates a high level of user satisfaction with the light quality and operation of the newly installed LED street lighting system. Users also experienced a significantly better light quality (see Figure 2) and a 100% reduction in mercury waste disposal requirements. The system is also 100% available and reliable without any failure since its installation.



Existing HPS Lamps

Newly Installed LED Street Lighting System

Figure 2. Light quality comparison.

Overall, the project has successfully demonstrated how existing street lighting units can be made more efficient using the current state-of-the-art technologies and prudent engineering in the design and operation of the lighting control systems. The outcome of this project also includes best practices and field experience that can help with the full-scale implementation in other DoD facilities around the U.S. The project is expected to lead to significant cost and energy savings, as well as contribute to reduce carbon dioxide emissions for DoD.

1.0 INTRODUCTION

This project entitled "bi-level demand-sensitive light emitting diode (LED) street lighting systems" was initiated in May 2010. The objective was to replace a set of streetlights at the Naval Surface Warfare Center (NSWC) – Carderock Division (NSWCCD) in West Bethesda, MD with a more energy efficient and intelligent street lighting system. This project demonstrated how existing street lighting units can be made more efficient using the current state-of-the-art technologies and prudent engineering in the design and operation of the lighting control systems. This report includes description of the demonstrated technology, assessment of the performance and cost of the demonstrated system, as well as field experience data that can help full-scale implementation to replicate this hardware/software deployment experience in other Department of Defense (DoD) facilities around the U.S.

1.1 BACKGROUND

In a typical DoD facility, outdoor lighting is used to provide for the safety of nighttime traffic operations for pedestrian pathways, roadways, parking lots, storage centers, housing, and areas around the base perimeter. Three major lamp types are common for outdoor lighting applications: high intensity discharge (HID), fluorescent, and incandescent. HID lamps are the most prevalent technologies being used for street lighting applications due to their high lumen output. The LED is emerging as the most energy efficient technology for lighting applications. When compared to its HID counterpart, LED can be dimmed without any impact on its life and color output. Through the use of a more energy efficient and demand-sensitive street lighting system—which is centrally controlled and monitored—we demonstrated in this demonstration project that there are high potentials in many DoD installations to deploy the LED lighting system for energy efficiency.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this demonstration project was to deploy an energy efficient LED street lighting system with an intelligent controller as a retrofit to an existing system at the NSWCCD in West Bethesda, MD.

Specifically, the objectives of this demonstration were:

1. To provide a technology demonstration to validate the performance and expected operational costs and benefits of the bi-level demand-sensitive LED street lighting systems for energy efficiency as described above;
2. To get the technology ready to be transferred by working with the Carderock Division Headquarters to evaluate technology acceptance, seek feedback, and provide appropriate guidance to assist in full-scale deployment;
3. To provide field experience data and an energy efficiency streetlight model that can be replicable in other DoD installations around the U.S. The findings and guidelines to be developed are expected to support and facilitate regulatory and end-user acceptance as well.

1.3 REGULATORY DRIVERS

There are many policies, regulations, executive orders, and legislative mandates that serve as drivers for implementing this new technology for energy conservation. The most significant drivers of energy efficiency in the DoD and other Federal buildings are:

- The Energy Policy Act of 2005
- Federal Leadership in High Performance and Sustainable Buildings. Memorandum of Understanding of 2006
- Executive Order 13423 Strengthening Federal Environmental, Energy, and Transportation Management of 2007
- The Energy Independence and Security Act of 2007
- Army Energy Security Implementation Strategy of 2009
- Executive Order 13514—Federal Leadership in Environmental, Energy and Economic Performance of 2009
- Unified Facilities Criteria (UFC) 3-400-01 Energy Conservation, with changes of 2008.

2.0 TECHNOLOGY DESCRIPTION

This section describes an overview of the demonstrated technology, and summarizes its advantages and limitations.

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The demonstrated technology is a smart bi-level demand-sensitive LED lighting system for outdoor street lighting applications that allows dimming as well as traffic sensing capability through a centralized controller. The highlights of the demonstrated system include the following characteristics:

- The use of LED light fixtures for energy saving, better light quality, and infrastructure savings
- The integration of streetlight controllers to enable bi-level and demand-sensitive features
- The integration of traffic sensors for detecting moving traffic
- The use of a smart server to perform light control

The building blocks of the demonstrated system include: (1) LED light fixtures, (2) streetlight controller, (3) traffic/photocell sensors, and (4) a smart server, as shown in Figure 3.

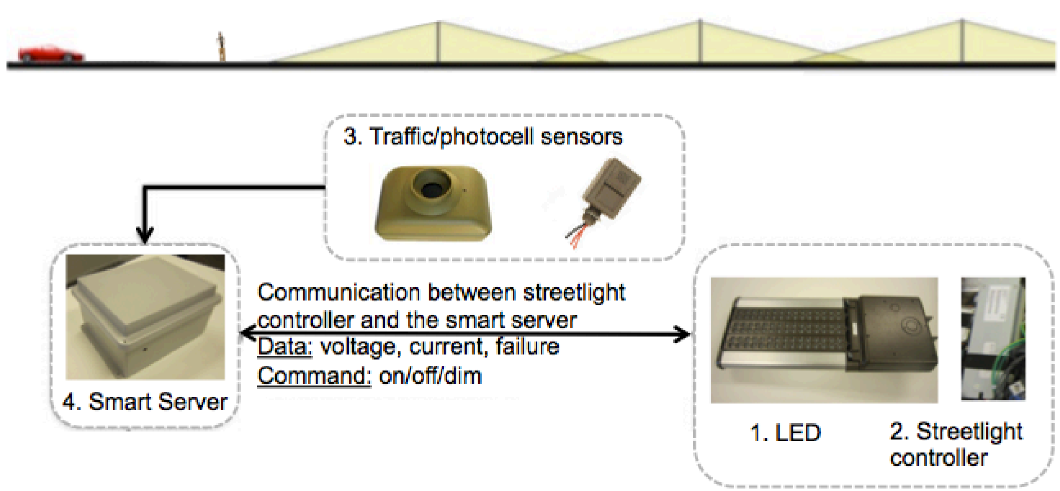


Figure 3. Technology overview.

The system is designed such that all LEDs are turned ON after the sunset (with a photocell sensor), and its light intensity is dimmed in two stages (80% intensity from 9pm to 11pm and 60% intensity from 11pm to 4am) to allow additional energy savings. As soon as foot/vehicle traffic is detected, the light intensity is set back to 100% for about five minutes. All LEDs are turned OFF simultaneously at sunrise.

One photocell sensor is used to detect sunset and sunrise times. It provides inputs to the smart server to allow controlling all LEDs to be ON after sunset and OFF after sunrise. Several traffic sensors are used to allow detecting foot and vehicle traffic at the demonstration site. These sensors provide input to the smart servers to allow turning up the light intensity of the LED units when foot/vehicle traffic is detected.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

By deploying the demonstrated technology, the issue of energy efficiency is addressed by the integration of *LED light fixtures* with a smart server for area light control, and *traffic sensors* for sensing traffic movements and adjusting lighting levels accordingly. Each light fixture has *a built-in streetlight controller* that allows the fixture to transmit its status information to *the SmartServer*.

In particular, the demonstrated LED street lighting system delivered the following advantages over the current technology being deployed at the Carderock Division Headquarters.

- *Superior luminous efficacy:* LEDs provide the best performance when compared with other traditional outdoor lighting technologies.
- *Superior light quality:* LEDs deliver superior light quality with a high color-rendering index (CRI). In addition, the use of white lights dramatically improves sensitivity and image quality captured by security cameras.
- *Longer Life:* LEDs are expected to last longer than 50,000 operating hours and require no electronic ballast. This is in contrast to high-pressure sodium (HPS) bulbs, which have to be replaced every 3 years (approximately 10,000 operating hours), and their ballasts need to be replaced every 6 years. This implies that there is no maintenance costs associated with bulb replacements for at least 12 years assuming average 11 hours/day operation.
- *Instantaneous response time:* While LEDs have instantaneous response time, it takes HID lamps some few minutes (2-7 minutes) during start up to achieve 90% of their full light output.
- *Reduction in waste disposal:* All HIDs contain Mercury, while LEDs are mercury free.
- *Wider range of voltage input:* Voltage drop is a typical problem experienced at the end of a long power distribution line, especially in a streetlight circuit. As the LED unit can accept wider input voltage range, i.e., 120-277Vac, than HPS (195-277Vac), this results in additional savings on electrical infrastructures (e.g., no need for capacitor banks) for a newly constructed street lighting project.

The limitation of the demonstrated LED street lighting system is summarized below.

- *Initial costs:* The cost of LED light fixtures is still high. However, with the maturity of technology, the cost is dropping at a rapid rate and the luminous output is also increasing every year.

3.0 PERFORMANCE OBJECTIVES

The demonstrated demand-sensitive LED technology was evaluated based on the following criteria.

3.1 QUANTITATIVE PERFORMANCE OBJECTIVES

Electricity consumption reduction – The metric is the annual electricity saving (kilowatt hour [kWh]). The success criterion is that the new LED street lighting system can deliver at least 50% or more electricity saving, compared to the existing HPS system.

Carbon footprint reduction – The metric is the annual carbon footprint saving in pounds (lbs) of carbon dioxide (CO_2). The success criterion is that the new LED street lighting system can deliver at least 50% or more in carbon footprint reduction.

Economic performance – The metrics include net present value (NPV), savings to investment ratio (SIR), payback period (year), and adjusted internal rate of return (AIRR). The success criteria are that (1) the new system provides lower NPV than the existing HPS system; (2) the new system delivers SIR of 1.5 or greater; (3) the new system delivers payback period of less than or equal to 7 years; and (4) the new system delivers AIRR of 5% or greater.

Illumination performance – The metric is the illumination level in footcandle (fc) measured within the area covered by the lamp. The success criterion is that the new street lighting system must meet the recommended maintained luminance values for collector roads in commercial environments as specified by the Illuminating Engineering Society of North America (IESNA).

Color temperature performance – The metric is the color temperature measurement in degrees Kelvin (°K) within the area covered by the lamp. The success criterion is that the color temperature of the new system is at least 4000°K as compared to 1600-2100°K delivered by the existing HPS units.

Mercury waste reduction – The metric is the amount of mercury in milligram (mg) saved by using the LED light fixtures. The success criterion is that the new street lighting system based on LED technology delivers 100% reduction in mercury disposal requirements.

3.2 QUALITATIVE PERFORMANCE OBJECTIVES

Qualitative satisfaction – The metric for this performance objective includes survey, feedback, and color photographs. Success criteria include positive feedback and high level of user satisfaction with the new street lighting system.

3.3 OPERATIONAL PERFORMANCE OBJECTIVES

System availability – The metric for this performance objective is the amount of time that the overall system is operational and ready to operate. The availability of the overall system can be derived from the availability of each component of the demonstrated system, including LED luminaires, their outdoor lighting controller (OLC), the SmartServer, traffic sensors and the photocell sensor. The success criterion is that the system has at least 95% availability.

System reliability – The metric for this performance objective is the amount of time the system performs as designed. These conditions include: All LED luminaires are switched ON at sunset; All LED luminaires are switched OFF at sunrise; All LED luminaires are dimmed at pre-selected times; and Selected LED luminaires increase their intensity to 100% when foot/vehicle traffic is detected; and their intensity is gradually decreased to the previous level after a pre-set time. The success criterion is that the system has at least 95% reliability.

3.4 PERFORMANCE OBJECTIVES AND RESULTS

Table 1 summarizes performance objectives, success criteria and demonstration results.

Table 1. Performance objectives and demonstration results.

Performance Objectives	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Reduction in electricity usage (kWh)	Energy savings from street lighting load (kWh)	Electrical measurements (watts, volts, amps) of old/new systems	>50% energy saving	~ 74% electricity savings
Reduction in carbon footprint (lbs of CO_2)	Reduction in carbon emission (lbs of CO_2)	Electricity consumption (kWh); and CO_2 emission rate (lbs/kWh)	> 50% reduction in carbon footprint	~ 74% CO_2 emission reduction
Lower cost of ownership over the lifetime	- NPV - SIR - Payback period - AIRR	Electricity consumption (kWh); electricity rate schedule ($/kWh); maintenance (man-hours or $/year)	The new system is evaluated based on the following criteria: - $NPV_{LED} < NPV_{HPS}$ - SIR >= 1.5 - Payback <= 7 yrs - AIRR >= 5%	- NPV_{LED} ($27,291) < NPV_{HPS} ($35,959) - SIR = 2.15 - Payback = 6 yrs - AIRR = 9.77%
Illumination levels	Illumination level	Illumination levels in fc	Average luminance >= 0.8 fc	1.4 fc during full intensity; 0.86 fc during dimmed state
Color temperature performance	Correlated color temperature (CCT)	Color temperature measurement (°K)	CCT >= 4000°K compared to existing CCT of 1600-2100°K	> 4000°K
Reduction in mercury waste	Amount of mercury in mg	Mercury content in existing lamps	100% reduction in mercury disposal requirements	100% reduction in mercury disposal requirements
Qualitative Performance Objective				
User acceptance and light quality	Survey, feedback, photographs	Feedback from individuals, including level of security and comfort, light quality, retrofit ability; photographs before and after the installation	Positive feedback and high level of user satisfaction	Positive feedback and high level of user satisfaction
Operational Performance Objective				
System availability	The amount of time the system is operational or ready to operate	System logs that record status of each component of the system	> 95% availability	100% availability
System reliability	The amount of time the system performs as designed	System logs that record LED output performance and traffic detection	> 95% reliability	100% availability

4.0 FACILITY/SITE DESCRIPTION

This section provides a concise summary of the site section process, site location and operations, site conditions, and site-related permits and regulations at the Carderock Division Headquarters of Naval Facilities Engineering Command (NAVFAC) Wash (NFW).

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The selected demonstration site is located at:

Location:	Naval Surface Warfare Center, Carderock Division Headquarters
Address:	9500 MacArthur Blvd., West Bethesda, MD 20817

The selected demonstration site is on Bill Morgan Road of the Carderock Division Headquarters.

The location of the site where the demonstration took place is illustrated in Figure 4.

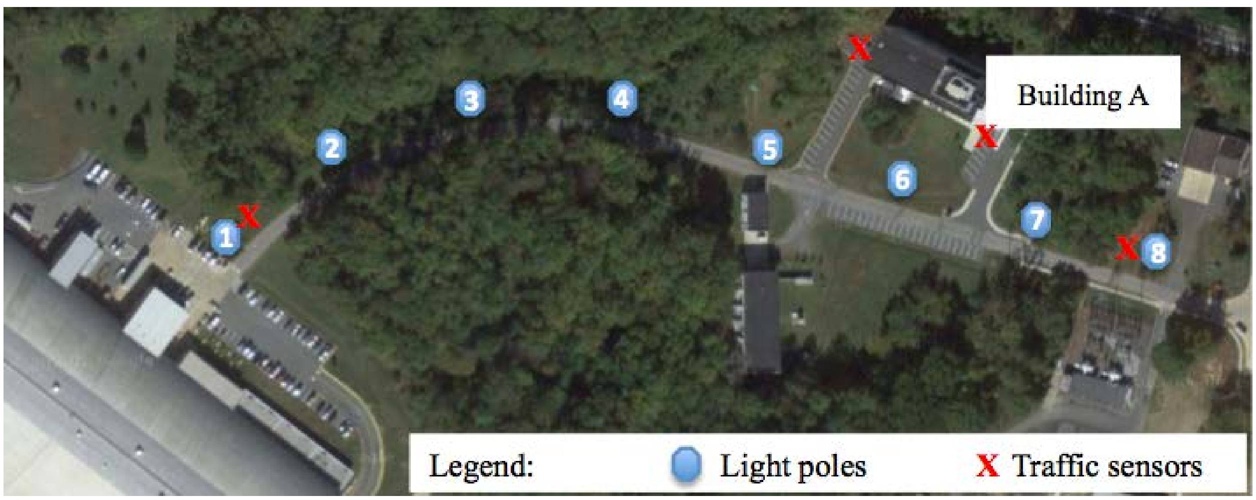


Figure 4. Aerial view of the demonstration site (Source: Google Earth).

4.2 FACILITY/SITE CONDITIONS

The service road of interests contained eight (8) HPS luminaires, as shown in Figure 4. Vehicle traffic is generally at a very low speed, i.e., 15 miles per hour. Foot traffic is generally generated by researchers who work in the research facility and commute to and from their housing inside the base. This traffic can be any time from 6am to 11pm, additionally, there can be people jogging very early in the morning, starting from 4am.

The eight (8) luminaires are fed by electricity drawn from the nearby building (Building A located in the middle of the street). The details of the street lamps are summarized below:

Lamps in use:	400W high-pressure sodium lamps (model# LU400)
System Voltage:	277 Volts
Pole Height:	30 feet
Pole Distance:	Approximately 175 feet apart

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5.0 TEST DESIGN

This section provides the detailed description of the system design and testing to be conducted to address the performance objectives described in Section 3.0.

5.1 CONCEPTUAL TEST DESIGN

5.1.1 Conceptual Test Design to Evaluate Quantitative Performance Objectives

Electricity consumption and carbon footprint: To measure the reduction in electricity consumption, a data acquisition system (DENT Instruments ElitePro) was installed at the distribution box feeding the streetlights (located in Building A). The purpose is to record time-series electric power consumption (voltage, current, real and reactive power of both the existing HPS lamps and the new system based on LED technology. Once the electricity consumption data is obtained, the carbon footprint can be calculated by multiplying the recorded electricity consumption (kWh) by the local CO_2 emission rate (lbs/kWh).

Economic performance: The life-cycle cost (LCC) analysis was conducted to compare the economic performance of the HPS and LED systems. Our economic performance analysis relies on the National Institute of Standards and Technology's (NIST) Building Life-Cycle Cost (BLCC) Program for Military Construction (MILCON) Analysis. To measure the economic performance of the demonstrated system, the following information was collected:

- Capital costs of the HPS and LED light fixtures ($) and associated control/monitoring infrastructure
- Maintenance costs (man-hour or $/year) of both HPS and LED street lighting units
- Electricity rate schedule for Carderock, MD ($/kWh)
- Annual electricity consumption (kWh/year) of both HPS and LED systems
- Service life of both HPS and LED light fixtures (years or hours)

Illumination and color temperature performance: To measure the illumination and color temperature performance, the Minolta XY-1 Chroma meter is used. The equipment readouts include illuminance value[1] in fc or lux, and correlated color temperature[2] in °K. The purpose is to record these parameters in the area under the street lighting units of interest in the luminaire test area as indicated in Figure 5.

The measurements were performed at specific locations (A1-K3) between two light poles, as shown in Figure 6. Along the street, between the two light poles, any two measurement coordinates (i.e., A1-B1, B1-C1, etc.) are 17.25 feet apart. The street of interest is about 26 feet

[1] Illuminance (fc) is a measure of the amount of light incident on a 1-square foot (ft^2) surface. One fc is equivalent to one lumen/ft^2, or approximately 10.764 lux. Fc is a common unit of measurement used to calculate acceptable lighting levels of indoor or outdoor spaces.

[2] CCT is a parameter used to characterize the spectral properties of a light source. The standard unit is °K. Lower color temperature (<3000°K) appears yellowish white, while higher color temperature (>5000°K) appears blueish white.

in width. Across the street, the measurements start from the location right under the light poles to 26.25 feet away from the light poles at 8.75 feet increment (i.e., A1-A2, A2-A3, etc.).

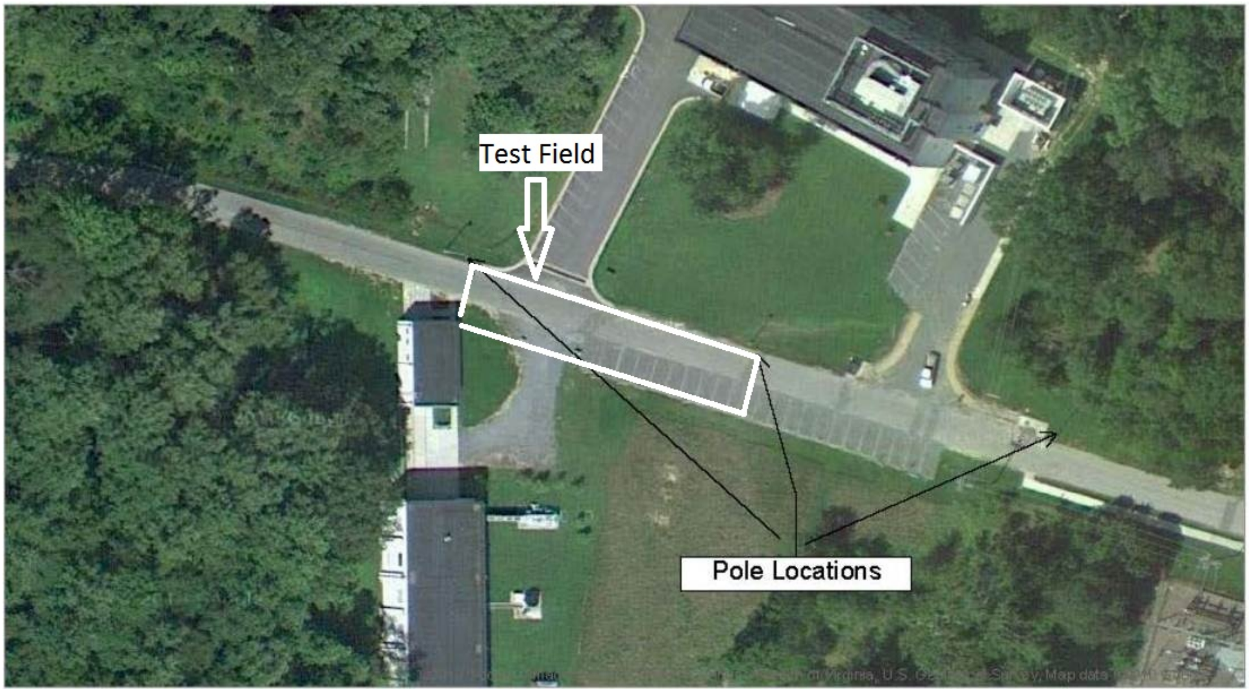

Figure 5. Overhead view of luminaire test area.

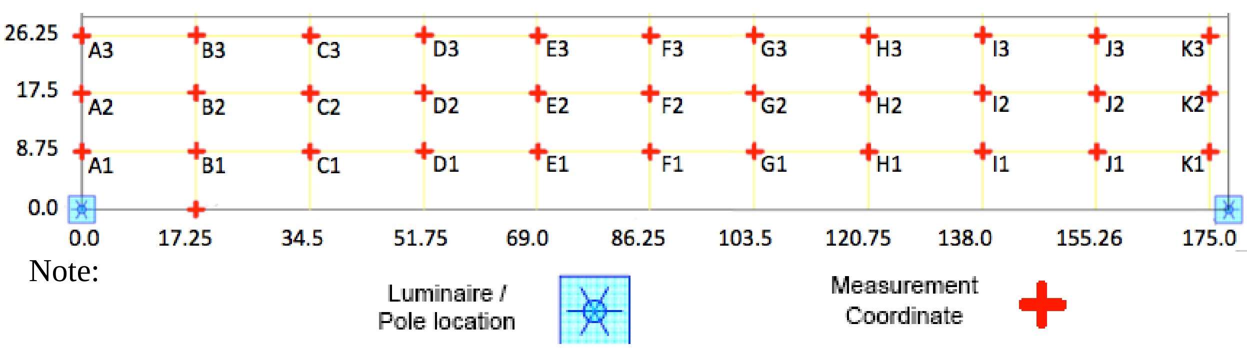

Figure 6. Illumination/color temperature measurement layout.

The measurements were performed twice: before and after the installation of the demonstrated LED street lighting system. This is to compare the illumination and color temperature characteristics of the existing HPS and the demonstrated LED units.

Mercury waste reduction: Since LED light fixtures do not contain mercury, mercury waste reduction can therefore be determined by estimating the amount of mercury used in the HPS lamps.

5.1.2 Conceptual Test Design to Evaluate the Qualitative Performance Objectives

A set of survey questions was used to evaluate the qualitative performance objectives, which include user satisfaction and acceptance in light quality. These questions include:

1) How satisfied are you with the overall performance of LED lighting?
2) How satisfied are you with the visibility improvement offered by the LED streetlights for you as a driver?
3) How satisfied are you with the visibility improvement offered by the LED streetlights for you as a pedestrian?
4) Do you feel that the new streetlights give off the right amount of light, or are they too bright or too dim?

In addition, the color photographs were taken in order to compare the light quality at the demonstration site before and after the installation.

5.1.3 Conceptual Test Design to Evaluate the System Availability and Reliability

The performance of the overall system was evaluated by determining the system availability and reliability. The system availability can be derived from the availability of each component of the demonstrated system. The system reliability, on the other hand, can be determined by the amount of time the system performs as designed. System logs that record component status and LED output performance are used.

5.2 BASELINE CHARACTERIZATION

5.2.1 Electricity Consumption Measurements

Power consumption data of eight (8) HPS light fixtures from January 2010 to December 2011 are summarized in Table 2.

Table 2. Power consumption data of 8 HPS light fixtures (January-December 2011).

Month	Average Voltage (Volts)	Average real power (W) per lamp	Average hours ON	Electricity consumption (kWh)
January 2011	277.2	428.5	13.8	1514
February 2011	278.5	430.8	12.7	1290
March 2011	279.5	432.5	11.9	1270
April 2011	278.1	429.3	10.7	1103
May 2011	278.3	427.3	9.7	1030
June 2011	276.2	425.0	9.0	890
July 2011	274.2	420.5	9.8	1034
August 2011	275.9	423.8	10.7	1119
September 2011	278.1	427.1	12.0	1232
October 2011	279.5	429.7	13.4	1431
November 2011	278.9	425.3	14.4	1468
December 2011	277.6	424.8	14.9	1572
Total kWh				14,953

5.2.2 CO_2 Emission

The average CO_2 emission factor (lbs/kWh) for Maryland was used to multiply the total electricity consumption (kWh) of the street lighting systems of interest to obtain the total CO_2 emission of HPS units in lbs. The CO_2 emission factor for Maryland is provided in the NIST's BLCC program at 1.454 lbs/kWh. Therefore, eight HPS lamps generated 14,953 kWh*1.454 lbs/kWh = 21,742 lbs of CO_2/year.

5.2.3 Illumination Measurements

The illumination (fc) measurements were taken on October 26, 2010 at 4:30am in the luminaire test area, as shown in Figure 7.

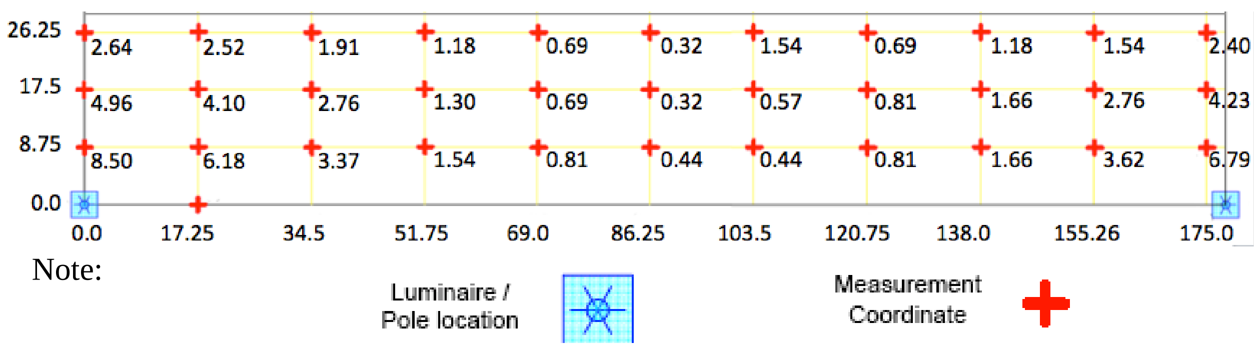

Figure 7. Illumination measurement (fc) as a function of distance in feet along the street (x-axis) and across the street (y-axis).

5.2.4 Color temperature Measurements

Illumination level in fcs is presented in Figure 8.

The CCT measurements in °K were taken on the same day, as presented in Figure 8.

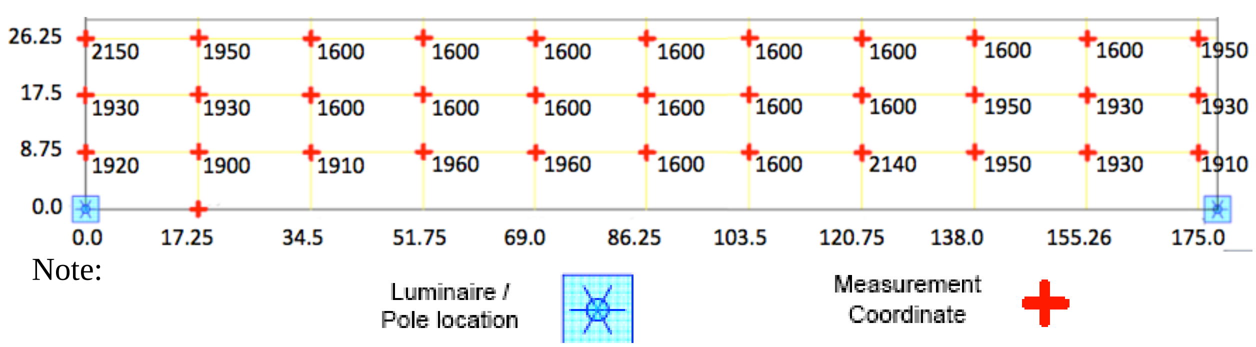

Figure 8. CCT measurements (°K) as a function of distance in feet along the street (x-axis) and across the street (y-axis).

Figure 9 is a photograph that illustrates the light quality of the existing HPS lamp, taken at the site on December 14, 2010.

Figure 9. Light quality of the existing HPS streetlight, taken at Carderock on December 14, 2010

5.2.5 Mercury in HPS Lamps

According to the manufacturer data, each of the existing HPS lamps used in Carderock, model LU400, contains approximately 11-30 mg of mercury.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

The demonstrated system comprises the following technology components:

1. Eight (8) LED light fixtures to replace existing HPS luminaires;
2. Eight (8) street light controllers installed at the base of each light pole;
3. Four (4) traffic sensors (see locations in Figure 10); one (1) motion detector receiver based unit located outside on the northwest corner of Building A; and one (1) photocell switch located outside of Building A; and
4. One (1) SmartServer located inside Building A.

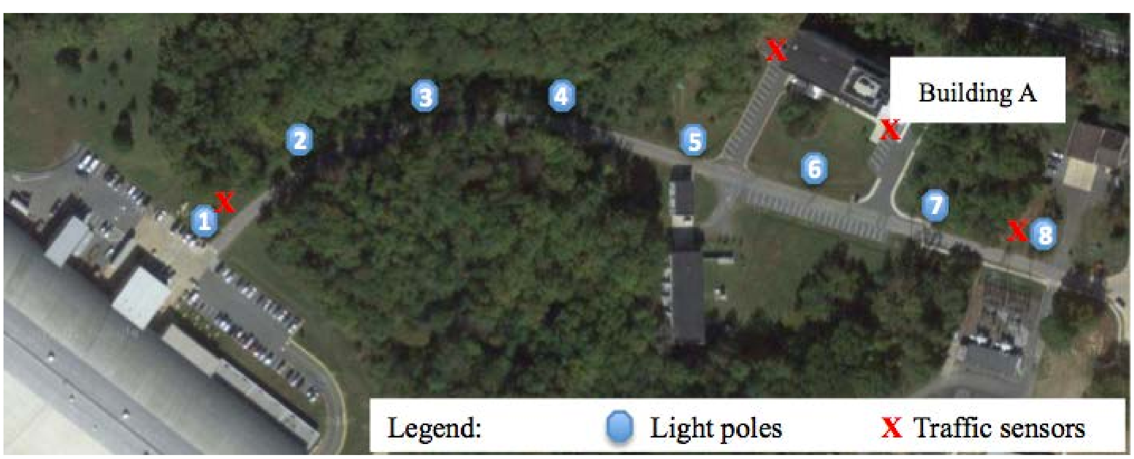

Figure 10. Layout of technology components (Source: Google Earth)**.**

5.4 OPERATIONAL TESTING

This demonstration project involves the following steps, as summarized in Table 3.

Table 3. Project timeline

Task	Date
Task 1: Initial field visit	May 2010
Task 2: Pre-installation monitoring	August 2010 – December 2011
Task 3: Technology integration and controller development	August 2010 – September 2011
Task 4: Pre-factory acceptance testing	September 2011 – December 2011
Task 5: Demonstration plan submission	August 2011
Task 6: System installation and adjustment	December 2011 – March 2012
Task 7: Post-installation monitoring	January 2012 – May 2013
Task 8: Final report submission	October 2013

5.5 SAMPLING PROTOCOL

To ensure a thorough evaluation of performance parameters, adequate volume of data were collected.

- Electricity usage readings were taken every five (5) minutes.
- For the illumination and CCT measurements, the sampling protocol employed was based upon the IESNA measurement guideline LM-50-99: "Guide for Photometric Measurements of Roadway Lighting Installations."
- Redundant data sampling was incorporated in the procedure to ensure the quality assurance in case of any spikes or bad data reading.
- All equipment was also calibrated according to the instructions provided in the handbooks from the respective manufacturers.

5.6 SAMPLING RESULTS

5.6.1 Electricity Consumption Measurements

Power consumption data of eight (8) LED light fixtures from January 2012 to December 2012 are summarized in Table 4.

Table 4. Power consumption data of 8 HPS light fixtures (January-December 2011).

Month	Average Voltage (Volts)	Average real power (W) per lamp	Average hours ON	Electricity consumption (kWh)
January 2012	278.3	122.0	14.8	443.9
February 2012	281.3	130.6	12.7	384.6
March 2012	280.3	111.9	11.5	319.3
April 2012	281.7	107.6	10.2	264.2
May 2012	253.1	109.9	9.3	253.1
June 2012	276.4	107.7	8.4	218.3
July 2012	274.0	107.9	9.0	231.9
August 2012	278.1	112.0	9.9	274.5
September 2012	280.2	116.5	11.0	308.7
October 2012	281.3	120.0	12.3	364.4
November 2012	280.9	124.6	13.3	396.8
December 2012	280.2	125.7	13.9	433.1
Total kWh				3,893.0

5.6.2 Illumination Measurements

The illumination (fc) measurements were taken in the luminaire test area when LED is at 100% intensity, as presented in Figure 11. These measurements were taken at around 4:30am on March 5, 2012.

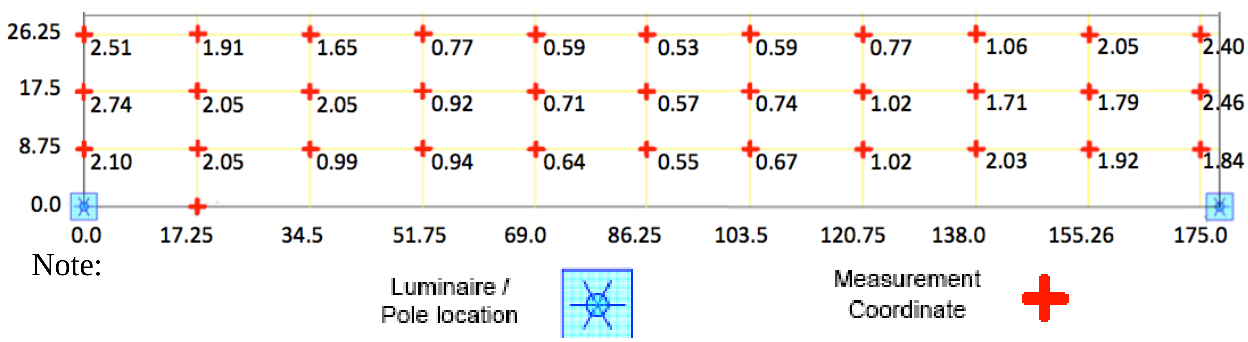

Figure 11. Illumination measurement (fc) of the LED luminaires at 100% intensity as a function of distance in feet along the street (x-axis) and across the street (y-axis).

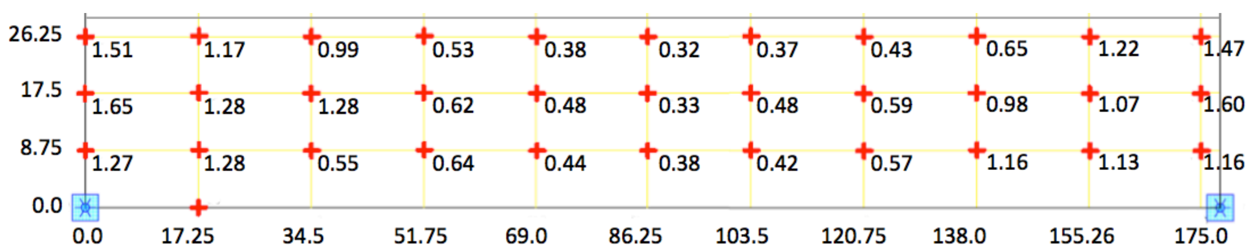

Figure 12. Illumination measurement (fc) of the LED luminaires at 60% intensity as a function of distance in feet along the street (x-axis) and across the street (y-axis).

5.6.3 Color Temperature Measurements

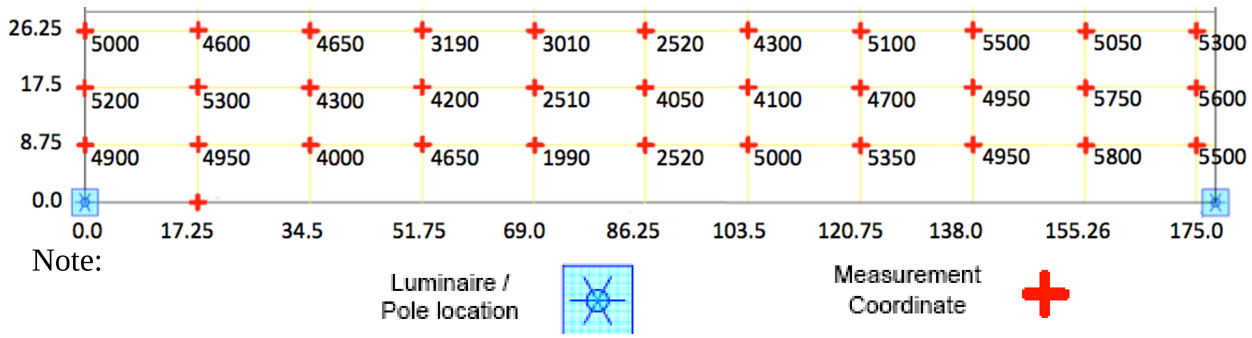

Figure 13. CCT measurements (°K) of LED luminaires at 100% intensity as a function of distance in feet along the street (x-axis) and across the street (y-axis).

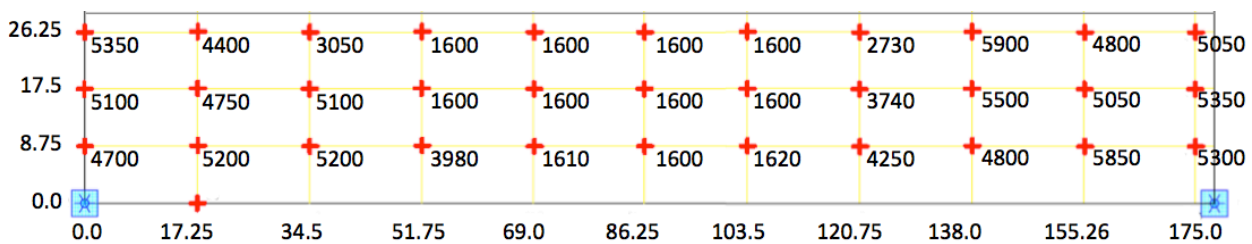

Figure 14. CCT measurements (°K) of LED luminaires at 60% intensity as a function of distance in feet along the street (x-axis) and across the street (y-axis).

5.6.4 Operation of HPS versus LED

Figure 15 shows the daily operation of HPS in comparison with that of LED luminaires in October 2012. Both figures show how motion sensors change the intensity of LED luminaires between 9pm and 4am from dimmed levels to full brightness with the presence of foot/vehicle traffic.

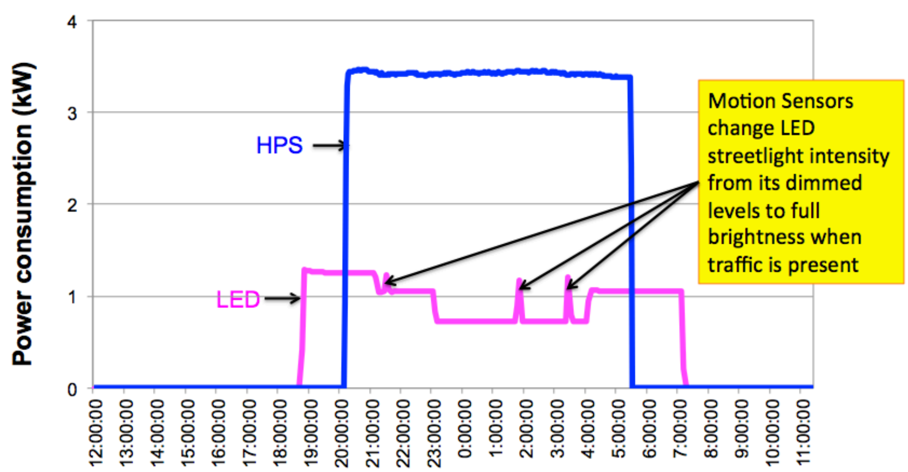

Figure 15. Daily operation of HPS (2011) versus LED (2012) on 16 October (multiple traffic detections).

5.6.5 Light Quality

Figure 16 and Figure 17 illustrate the light quality of the newly installed LED lamp, taken at the site on June 11, 2012. These are as opposed to the light quality of the HPS system, shown in Figure 9.

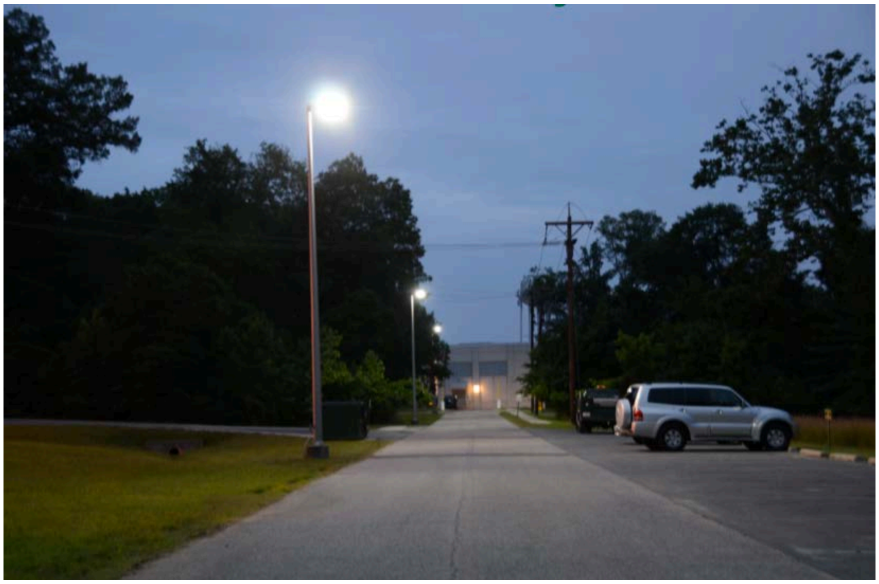

Figure 16. Light quality of the LED streetlight, taken on June 11, 2012 at 8:53pm (100% intensity).

Figure 17. Light quality of the LED streetlight, taken on June 11, 2012 at 9:14pm (80% intensity).

6.0 PERFORMANCE ASSESSMENT

The performance assessment was conducted for the system under demonstration. This is presented below according to the performance objectives listed in Table 5.

Table 5. Electricity consumption of HPS and LED street lighting systems.

Month	HPS Electricity Consumption (kWh) in 2011	LED Electricity Consumption (kWh) in 2012
January	1,514	443.9
February	1,290	384.6
March	1,270	319.3
April	1,103	264.2
May	1,030	253.1
June	890	218.3
July	1,034	231.9
August	1,119	274.5
September	1,232	308.7
October	1,431	364.4
November	1,468	396.8
December	1,572	433.1
Total	**14,953**	**3,893**

6.1 REDUCTION IN ELECTRICITY USAGE (KWH)

The electricity usage reduction can be determined by comparing the electricity consumption of the HPS units and that of the LED units during a one-year period. The table summarizes electricity consumption of HPS and LED luminaires.

The measurements indicate annual electricity savings of 14,953 – 3893 = 11,060kWh. This is equivalent to an average of 74.2% saving during a one-year period. This indicates that the performance objective (i.e., >50% electricity saving) is met for reduction in electricity usage.

6.2 REDUCTION IN CARBON FOOTPRINT (LBS)

After deriving the annual energy savings, the carbon footprint reduction (lbs) can be derived by multiplying the CO_2 conversion factor (lbs/kWh) for the area with the annual energy reduction (kWh) achieved. The CO_2 conversion factor for Maryland is 1.454 lbs/kWh. The annual CO_2 emission reduction is summarized in Table 6, which indicates that the performance objective (i.e., >50% CO_2 emission reduction) is met for reduction in carbon footprint.

Table 6. Comparison of annual electricity consumption and CO_2 emissions.

	HPS	LED	Annual savings
Annual Electricity Consumption	14,953 kWh	3893 kWh	11,060 kWh (~74% savings)
Annual CO_2 emission	21,742 lbs	5660 lbs	16,081 lbs (~74% savings)

6.3 ILLUMINATION ASSESSMENT

Based on the IESNA measurement guideline LM-50-99:

- Recommended average (AVE) maintained luminance values for collector roads in commercial areas is >= 0.8 fc
- Recommended average-to-minimum (AVE/MIN) value is < 4 to 1
- Recommended maximum-to-minimum (MAX/MIN) value is < 8 to 1

Illumination measurements of the HPS and LED lighting system are compared in Table 7.

Table 7. Illumination measurement in fc of the HPS and LED systems.

Illumination Measurements in fc	MIN	MAX	AVE	AVE/MIN	MAX/MIN
HPS	0.32	8.5	2.24	7.00	26.6
LED @ 100% intensity	0.53	2.74	1.40	2.64	5.17
LED @ 60% intensity	0.32	1.65	0.86	2.68	5.16

Apparently, the LED system meets or exceeds the industry standards as described above. Compared with its HPS counterpart, LED provides better illumination and luminance uniformity even in its dimmed stage. This indicates that the performance objective is met for illumination measurement.

6.4 COLOR TEMPERATURE PERFORMANCE

CCT measurements from the LED units at their full intensity (100%) and dimmed stage (60%) are compared with the baseline values obtained from the existing HPS-based lighting system. These measurements are summarized below:

Table 8. CCT comparison of HPS versus LED.

CCT in °K	Maximum CCT	Minimum CCT	CCT Range (area with no or low light pollution)
HPS	2140	1600	1600 – 2140
LED @ 100% intensity	5800	2510	4300 - 5800
LED @ 60% intensity	5850	1600	4700 - 5850

The results indicate that, while the maximum CCT values of LED units are higher than 5000°K, their minimum CCT values are between 1600 and 2510. The reason behind low CCT values is the light pollution from the HPS lamp located at Building A. Without the light pollution, e.g., in the area ±25-50 feet from the light poles, the CCT range of LED units range from 4300°K to 5850 °K. This indicates that the performance objective is met for color temperature performance.

6.5 REDUCTION IN MERCURY WASTE (MG)

In this demonstration project, over a study period of 12 years, the HPS bulbs are to be replaced 4 times or the total of 32 bulbs (for 8 HPS luminaires). Each HPS bulb at Carderock (model LU400) contains approximately 352-960 mg of mercury. Therefore, the amount of mercury waste reduction is estimated at over the 12-year study period. This is summarized in Table 9, which indicates that the performance objective is met for reduction in Mercury waste.

Table 9. Reduction in mercury waste.

	Base case (HPS)	Alternative (LED)	Savings from Alternative
Mercury in each light bulb	11-30 mg	0 mg	11-30 mg/lamp
Number of bulbs to be replaced during the study period of 12 years	8 bulbs every 3 years = 32 bulbs	-	352-960 mg

6.6 USER ACCEPTANCE AND LIGHT QUALITY

The acceptance level of the street lighting system under demonstration was evaluated by a survey involving the personnel working in the area. The survey was conducted on during the week of April 9-16, 2013. Thirteen (13) individuals responded to the survey. Survey results indicate that everybody either extremely satisfied or very satisfied with the overall performance and visibility improvement offered by the new LED street lighting system. Color photographs showing HPS light quality (Figure 9) and LED light quality (Figure 16-17) indicate that HPS offers yellowish light, while LED delivers white light – which improves visibility for both pedestrians and surveillance cameras. The result indicates that the performance objective is met for user acceptance and light quality.

6.7 SYSTEM AVAILABILITY

The availability of the overall system was derived from the availability of each component of the demonstrated system, including LED luminaires, their OLC, the SmartServer, traffic sensors and the photocell sensor. Recorded data indicate that all components work as expected, with the following observations:

- There were a couple of electricity outages at the demonstration site when the new LED street lighting system was already installed. The outages caused all voltage/power readings to become zero. These were not counted toward system availability, as they were a site-wide event.
- All system components (LED luminaires, OLCs, SmartServer and traffic/photocell sensors) demonstrated no failure during the 1-year post-installation monitoring period.

This implies 100% system availability during the post-installation monitoring period, thus the performance objective is met for system availability.

6.8 SYSTEM RELIABILITY

System reliability was measured by the amount of time the system performs as designed. Recorded data indicate that:

- LED luminaires were switched ON at sunset;
- LED luminaires were switched OFF at sunrise;
- LED luminaires were dimmed at pre-selected times;
- LED luminaires increased their intensity to 100% when foot/vehicle traffic was detected; and their intensity was gradually decreased to the previous level after a pre-set time.
- The system was also function as expected during rain and snow.

This implies 100% system reliability, thus the performance objective is met for system reliability.

7.0 COST ASSESSMENT

This section provides summary of cost information for the technology demonstration at the site.

7.1 COST MODEL

The cost components tracked are summarized in Table 10.

Table 10. Cost model for the HPS versus LED street lighting systems.

Cost Element	Data Tracked During the Demonstration	Costs
Hardware capital costs	Luminaires and OLCs traffic/photocell sensors	HPS hardware capital costs (for new installation) • HPS luminaires = 8*$400/lamp = $3200
		Hardware capital costs for LED • LED luminaires + OLCs = 8*$1195/lamp = $10,400 • SmartServer (can control up to 200 luminaires) = $750 • Photocell sensor = $100 • Traffic sensor = $460
Installation costs	Lamp installation and electrical wiring	• Lamp installation = $4900 • Electrical wiring = $6150 These costs are applicable to both HPS and LED for new installation.
Facility operational costs	Estimate based on electricity consumption during the demonstration	HPS electricity consumption = 14,953 kWh/yr @ 11.83 c/kWh = $1769/year
		LED electricity consumption = 3893kWh/yr@11.83c/kWh = $460/year
Maintenance cost	Frequency of required maintenance; labor and material per maintenance action	Maintenance cost for HPS • Light bulb: $50 every 3 years Ballast: $200 every 6 years Labor: $50/hr Y3: 8 bulb replacement = $400 Labor = 5hrs*$50/hr = $250 Y6: 8 bulb & 8 ballast replacement = $2000; Labor = 8hrs*$50/hr = $400 Y9: same as Y3
		Maintenance cost for LED • No maintenance required for bulb/ballast replacement; Change batteries for traffic sensors (every year): Battery = $9/4units = $9; Labor = 1hr*$50/hr = $50.
Hardware lifetime	Estimate hardware life time	Lifetime for HPS: 3 years - bulbs; 6 years - ballasts
		Lifetime for LED: 12 years or more

7.2 COST DRIVERS

At the time of the demonstration project, the LED luminaire was acquired at $1195 each. This cost is expected to come down significantly in the next few years. Additional hardware capital costs of the LED project included the SmartServer, traffic and photocell sensors. One SmartServer with one set of photocell/traffic sensors can be used to control up to 200 luminaires.

Therefore, additional saving can be achieved when the equipment is used to control a large number of luminaires, as opposed to eight luminaires in the demonstration project.

The installation and maintenance costs are site-specific, and can be costly. At Carderock, all electrical work must be performed by State licensed and bonded contractors who have registered with the facility manager. Such contractors are required to have security clearances and access to the base and work under the supervision of the Facilities Division. As a result, for the demonstrated demonstration project, only one group of electricians was qualified to perform the work, which could drive up costs for installation and electrical wiring at the base.

Electricity rate (c/kWh) also varies significantly by state. The demonstration site is located in Maryland, with the estimated electricity rate of 11.83 c/kWh. The electricity rate could be as high as an average of 33.96 c/kWh in Hawaii (as of March 2013)

7.3 COST ANALYSIS AND COMPARISON

The estimated life-cycle cost analysis of the demonstrated technology, focusing on the NPV, SIR, payback period and AIRR, was determined using the NIST BLCC Program for MILCON Analysis. Assumptions made for the cost analysis are: The analysis is for new installation; Study period is 12 years; Discount rate is 3%; and Discount and escalation rates are based on real dollars. Using the data in Table 10 as inputs to the NIST's BLCC program, Table 11 illustrates the net present value comparison over the study period of 12 years.

Table 11. NPV comparison over the 12-year life (new installation).

	Base case (HPS)	Alternative (LED)	Savings from Alternative
Initial investment cost	$14,350	$21,920	-$7570
Energy consumption cost	$17,909	$4663	$13,247
Replacement cost	$3700	$708	$2992
Total present value life-cycle cost	**$35,959**	**$27,291**	**$8669**

The results indicate that the demonstrated LED system has proven to provide lower cost of ownership over the system lifetime. This is due to lower monthly electricity bills and lower maintenance requirements. Additional results from NIST's BLCC indicate that:

- The SIR of the LED project is 2.15.
- The AIRR of the LED project is 9.77%
- The payback period is 6 years.
- Life-cycle electricity saving is 132,690 kWh during the project life of 12 years.
- Life-cycle CO_2 emission saving is 192,955 lbs during the project life of 12 years.

8.0 IMPLEMENTATION ISSUES

The following issues were faced during the demonstration:

1. *Restrictions on physical access to the site* – At Carderock, visitors must be escorted in the base at all times. In general, the permit to access the base during working hours is obtainable at the Visitor Center by the gate, upon providing valid identification and the name of the host/contact person on base. For access during non-working hours, a request must be submitted to the security at the base at least 2 weeks in advance of the visit by the host/contact person on behalf of visitors.
2. *Restrictions on bringing equipment to the site* – All electrical and electronic tools and equipment including computers must be registered and approved by the security at the base before bringing into Carderock. Visitors must fill out a form indicating the equipment name, model, serial number and intended uses on the base. A minimum of one week is required for approval.
3. *Restrictions on wireless communications* – The facility does allow the operation of some wireless equipment but under very strict conditions. A system data sheet must be completed for each wireless transmitting and receiving component and submitted ahead of time to the Space and Naval Warfare Systems Command (SPAWAR) for approval.
4. *Restrictions on remote access from outside the base to the equipment* – For security reasons, the Base does not allow direct Ethernet link to the outside world for accessing datalogging devices and the SmartServer. This has prevented us from remote logging to the LED lighting system and undertaking any remote monitoring as well as system updating and troubleshooting tasks. Hence, the Virginia Tech engineer must make once a month trip to the facility to download the electrical measurement data from the data logger and the operation data from the SmartServer.
5. *Restrictions on installation contractors* – All electrical work on the base must be performed by State licensed and bonded contractors who have experience working on the base. Such contractors must have security clearances and work under the supervision of the Facilities Division.
6. *In-rush current* – At the beginning of new LED installation, we noticed that one or two LEDs were left ON at the dimmed stage during the day. After investigating the issue, this was found to be due to the high in-rush current created when the LED driver was switched ON, which caused the contacts of some of the relays to shut at times. The light controllers were upgraded that can sustain the high in-rush current created by the LED driver. Following this design change the LED system operated without a glitch.

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APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization	Phone E-Mail	Role In Project
Dr. Saifur Rahman	Virginia Tech Advanced Research Institute (ARI) 900 N. Glebe Road Arlington, VA 22203	Phone: (571) 858-3300 E-mail: srahman@vt.edu	Principal Investigator
Dr. Manisa Pipattanasomporn	Virginia Tech Advanced Research Institute (ARI) 900 N. Glebe Rd, Arlington, VA 22203	Phone: (571) 858-3302 E-mail: mpipatta@vt.edu	Co-Principal Investigator
Dr. Isaac Flory	Dept of Eng Technology Old Dominion University 5115 Hampton Blvd Norfork, VA 23529	Phone: (757) 683-6560 E-mail: iflory@odu.edu	Co-Principal Investigator
Mr. Greg Cancila	Naval Surface Warfare Center, Carderock Division (NSWCCD) Philadelphia 5001 S. Broad Street Philadelphia, PA 19112	Phone: (215) 897-7607 E-mail: Gregory.cancila@navy.mil	Point of contact at Carderock

ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605
(571) 372-6565 (Phone)
E-mail: estcp@estcp.org
www.serdp-estcp.org